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Does TV Col Have the longest Recorded Positive Superhumps?

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Abstract. Re-examination of extensive photometric data of TV Col reveals evidence for a permanent positive superhump. Its period (6.4 h) is 16 percent longer than the orbital period and obeys the well known relation between superhump period excess and binary period. At 5.5-h, TV Col has an orbital period longer than any known superhumping cataclysmic variable and, therefore, a mass ratio which might be outside the range at which superhumps can occur according to the current theory. We suggest several solutions for this problem.

1. Introduction

1.1. Permanent superhumps

Permanent superhump systems compose a new subclass of cataclysmic variables (CVs), whose existence was established only in the nineties. Systems that belong to this group have quasi-periodicities slightly shifted from their orbital periods, in addition to the binary periods themselves. Unlike SU UMa systems (see Warner 1995 for a review on SU UMa systems and CVs in general), which show this behaviour only during superoutbursts, in permanent superhump systems the phenomenon is observed during their normal brightness state. According to Osaki (1996), permanent superhumpers differ from other subclasses of non-magnetic CVs by their relatively short orbital periods and high mass transfer rates, resulting in accretion discs that are thermally stable but tidally unstable. Retter & Naylor (2000) provided observational support for this idea.

The '**positive superhump**', periodicity which is a few percent larger than the orbital period, is explained as the beat period between the binary motion and the precession of an eccentric disc in the apsidal plane. Periods slightly shorter than the orbital periods have also been seen in several systems. They are known as '**negative superhumps**' (Patterson 1999). The observations show a roughly linear relation between the positive superhump period excess as a fraction of the binary period and the binary period (Stolz & Schoembs 1984). Negative superhumps seem to obey a similar rule (Patterson 1999). It has been suggested that negative superhumps are generated by the nodal precession of the accretion disc (Patterson et al. 1993; Patterson 1999); however, there are some theoretical difficulties with this idea (e.g. Murray & Armitage 1998).

1.2. Periodicities in TV Col

The periodicities detected so far in TV Col and their common interpretations are (Motch 1981; Hutchings et al. 1981; Schrijver, Brinkman & van der Woerd 1987; Barrett, O'Donoghue & Warner 1988; Hellier, Mason & Mittaz 1991; Hellier 1993; Augusteijn et al. 1994):

- 4 day - the nodal precession of the accretion disc
- 5.5 hr - the orbital period
- 5.2 hr - the negative superhump (the beat between the orbital period and the nodal precession)
- 32 min - the spin period

There seems to be a strong connection between positive and negative superhumps. Light curves of many permanent superhumpers show both types of superhumps. In addition, period deficits in negative superhumps are about half period excesses in positive superhumps (Patterson 1999): $\epsilon_{negative}{\approx}{-0.5}\epsilon_{positive}$, where $\epsilon{=}(P_{superhump}{-}P_{orbital})/P_{orbital}$. We, therefore, decided to look in available photometric data on TV Col for positive superhumps, which would be predicted to have a period near 6.4 h. Here we report the finding of such a periodicity as initially announced by Retter & Hellier (2000).

2. Observations

We have reanalysed existing optical photometry that was presented by Barrett et al. (1988); Hellier et al. (1991); Hellier (1993); Hellier & Buckley (1993) and Augusteijn et al. (1994). This dataset contains 77 nights of observations obtained during 1985-1991 from eight separate runs. The telescopes used were the South African Astronomical Observatory (SAAO) 0.75-m & 1-m telescopes and the Dutch 0.91-m telescope at the European Southern Observatory (ESO). Runs with mini-outbursts (see e.g. Augusteijn et al. 1994) were rejected for obvious reasons. The 1989 January run is the best among the six remaining datasets. It consists of six successive nights, each longer than six hours; no outburst occurred during the run; the observations were carried out with a CCD (rather than a photometer) and with the largest telescope among the three used, accumulated more photons ('clear' filter), and had the longest exposure times (less dead-time), thus giving the best signal to noise ratio among all datasets.

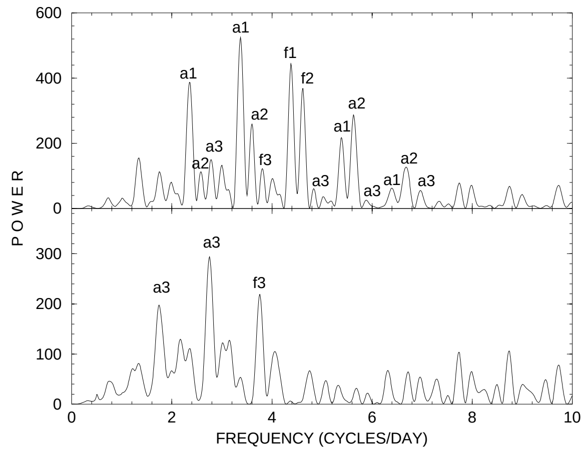

Figure 1. Power spectra of the 1989 January run. Upper panel (a): In addition to the two previously known periods – the orbital period (f1) and the negative superhump (f2), there is a third structure of peaks centered at a 1-d alias of 6.4 h (f3); 'ai' (i=1,2,3) represent aliases of 'fi' correspondingly; Lower panel (b): After subtracting f1 and f2, the candidate period is still present.

3. Analysis

In Fig. 1a the power spectrum of the data from the best run is shown. The detrending was done by subtracting the mean from each night. In addition to the two known periods (5.5 h and 5.2 h, marked as f1 and f2 respectively) and their aliases, there is a third peak (labelled f3) and its aliases. These peaks also appear in the raw power spectrum when no detrending method is used. After fitting and subtracting the two known frequencies (f1 and f2), f3 and its 1-d alias become the two strongest peaks in the residual power spectrum (Fig. 1b). We chose f3 as the real period rather than its 1-d alias (which is stronger) for reasons given below (see Fig. 2). Furthermore, the same relative peak strengths is seen in the orbital period, where the alias is stronger than the true period.

We ran a few tests to check the significance of the candidate period, 0.265(3) d. Here we give details of what we consider the most important test. We tried to assess the probability that correlated noise could be responsible for the candidate periodicity. In the absence of a model for the correlated noise, the best test is to use the repeatability in different datasets. Given that we found a period in the best set, we can ask how likely it is that the strongest period in the other datasets (after the known periods had been subtracted) would be consistent with it. The probability of the highest peak in another dataset being, by chance, compatible with the candidate period in the best set is 0.08. This was calculated from (i) the frequency error for the candidate period, which implies that the peaks are identical if they are within 0.04 day^{-1}, and (ii) the range over which it could occur taken as the spacing of the 1 day aliases (1 day^{-1} is the maximum range over which periods are truly independent). The period discovered in the best set was seen in two of the remaining five datasets. We thus used the binomial

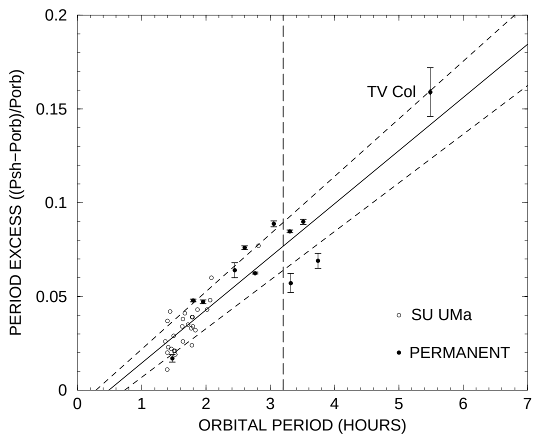

Figure 2. The relation between superhump period excess (over the binary period) and binary period in superhump systems. Empty circles correspond to periods in the SU UMa systems. Filled circles represent permanent superhumpers. The solid line represents the linear fit to the data. The two tilted dashed lines show the 1-σ error. TV Col obeys the relation. The upper edge of the period gap (as defined by Diaz & Bruch 1997) is marked by the vertical long-dashed line.

distribution to find that the probability of this occurring by chance was formally 5 percent. However, two of the sets that do not show the period are those with the shortest runs each night, and thus the lowest data quality. Thus the 95% significance value should be regarded as a lower limit.

4. Discussion

The photometric data show evidence for a periodicity of 0.265 d in addition to the previously known periods. The repeatability of the peak in three independent datasets makes it 95% significant. In addition, the better the data are, the more the period stands out of the noise. Moreover, it has almost exactly the value predicted from the Stolz & Schoembs (1984) relation (updated by Patterson 1999) shown in Fig. 2. TV Col has already been classified as a permanent superhump system because its 5.2-h period was interpreted as a negative superhump. In addition, the new period and the negative superhump obey the relation between the two types of superhumps (Section 1.2). Therefore, the new period is naturally interpreted as a positive superhump.

According to theory superhumps can appear only in CVs with small mass ratios – q=$M_{donor}/M_{compact}$<0.33. Hellier (1993) concluded, however, that q=0.62-0.93 from a spectroscopic analysis of the system, but this depended on an interpretation of the emission lines that may not be correct. Using the superhump excess, we find: q=0.95±0.10 – well above the 0.33 limit suggested by the hydrodynamic simulations, and consistent with the values estimated by Hellier. The mass ratio in TV Col may thus be above the theoretical limit, perhaps due to its strong magnetic field. Alternatively, TV Col may be an extreme system, with a very massive white dwarf near the Chandrasekhar mass ($1.44\mathbf{M}_{\odot}$), and / or an undermassive secondary star.

5. Summary

- Analysis of previously published photometric data reveals evidence for the presence of an additional period (6.4 h) in the optical light curve of TV Col. This periodicity can be identified with the positive superhump.
- Our findings support the classification of TV Col as a permanent superhump system. TV Col has, therefore, the longest known superhump period among all CVs.
- TV Col offers a unique opportunity to test and reject some of the models as it extends the superhump regime to periods far beyond the predicted values, where the difference between the models become significant. The mass ratio of TV Col might exceed the limit for superhump systems allowed by hydrodynamic simulations. Therefore, a confirmation for our findings is urgently required by further observations.

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